UCRL-CONF-203918

LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

A Filter-Fluorescer Diagnostic System (FFLEX) for the National Ignition Facility (NIF)

J.W. McDonald, R.L. Kauffman, J.R. Celeste, M.A. Rhodes, F.D. Lee, L.J. Suter, A.P. Lee, J.M. Foster, G. Slark

April 30, 2004

15th Topical Conference on High-Temperature Plasma Diagnostics
San Diego, CA, United States
April 19, 2004 through April 22, 2004

Disclaimer

A Filter-Fluorescer Diagnostic System (FFLEX) for the National Ignition Facility (NIF)

J.W. McDonald, R.L Kauffman, J.R. Celeste, M.A. Rhodes,
F.D. Lee, L.J. Suter and A.P. Lee
Lawrence Livermore National Laboratory

J. M. Foster and G. Slark
Aldermaston Weapons Establishment
Aldermaston, Reading, RG7 4PR, UK

Abstract

An early Filter-Fluorescer Diagnostic System (FFLEX) is being fielded at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL) to measure the amount of hard x-rays (20 < $h\nu$ < 150 keV) generated in laser fusion experiments. From these measurements we hope to quantify the number of hot (20 to 50 keV) electrons produced in laser fusion experiments. The Measurement of hot electron production is important for ignition experiments because these electrons can preheat the fuel capsule. Hot electrons can also be employed in experimentation by preheating hydrodynamic packages or by driving plasmas out of equilibrium. The experimental apparatus, data collection, analysis and calibration issues are discussed. Expected data signal levels and rates are predicted and discussed.

Introduction

The Aldermaston Weapons Establishment (AWE) FFLEX which has been operating at HELEN[1] for years is being fielded at the NIF and is expected to produce data by August of 2004. The FFLEX device consists of eight filter fluorescer channels[2]. The purpose of the Filter-Fluorescer diagnostic system is to measure absolute, time-integrated, high energy x-ray spectra from laser irradiated targets to aid in determining electron preheat levels. System channel coverage is from 18 to 150 keV using eight absolutely calibrated channels that are 2 to 50 keV wide for x-ray energies < 100 keV and about 100 keV wide for x-ray energies > 100 keV. This system could be configured to measure higher and lower energies with different filter-fluorescer combinations. To measure lower energies the system can be operated under vacuum to reduce attenuation of the x-rays by air.

Experimental setup

The FFLEX filter-fluorescer channels can be configured to measure x-ray at various energies with narrow band-pass. Figure 1 depicts one of the eight FFLEX channels. In the current configuration the low energy x-rays are limited by the vacuum window thickness requirements, therefore there is no need to operate the system under vacuum.

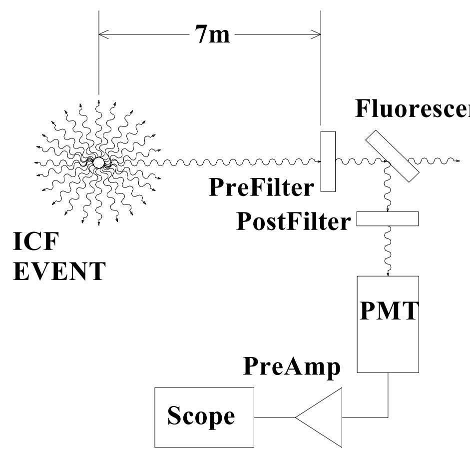

Figure 1 Schematic representation of FFLEX.

As configured FFLEX will provide limited time information. The rise time of the PMT signal is primarily determined by the scilintator material, NaI(Tl), and is on the order of 230 ns while the fall time is on the order of 100µs. The expected PMT output signal is depicted in figure 2. Experimental control of the hardware is accomplished by a network controllable PC over the GPIB buss and local network. The response for channel 5 is depicted in Figure 3.

FFLEX uses charge-sensitive pre-amplifiers, powered from a +/- 15 V supply rails. Maximum output signal is 10 V, and the expected noise level should be typically ≤ 50 mV. FFLEX should be configured to give output signals in the approximate range 0.1–10 V. This condition is achieved for all but two channels in Figure 2, with E_{hot} = 100 J and T_{hot} in the range 20–60 keV. Experiments yielding greater hot-electron energy (greater absorbed laser energy, or increased hot-electron fraction) will require a reduction of sensitivity for some (but not necessarily all) channels. A reduction of sensitivity by up to an order of magnitude may be achieved simply be reduction of photomultiplier bias voltage or pre-amplifier sensitivity for the present FFLEX configuration. The present pre-amplifiers have variable gain, obtained by switch-selection of different feedback capacitors providing a factor-of-5 reduction of gain. This, together with a modest reduction of bias voltage will enable the sensitivity of the present configuration to be reduced by more than an order of magnitude. FFLEX would then be immediately applicable to experiments with 16 kJ laser energy and f_{hot} = 10 % (or equivalent conditions). Greater reduction of sensitivity by this means may require us to address the possible space-charge limitation of photomultiplier output current, but other means of effecting a reduction of sensitivity (such as reduced aperture between fluorescer and scintillator, or the use of a neutral density filter between scintillator and photomultiplier) are of course readily available.

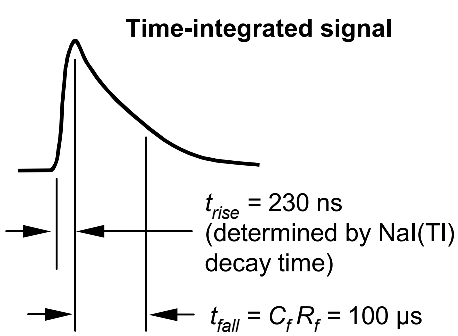

Figure 2 Expected PMT output signal.

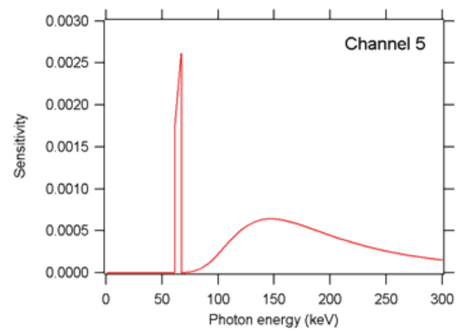

Figure 3 Channel 5 response plotted vs photon energy

Data collection

Waveforms from the various oscilloscope channels are to be collected by a web controlled PC located near the NIF vacuum chamber. The data will be then saved to a central NIF data bank that allows web access of files referenced by shot number. These data files, stored in HDF 1.4 and HDF 1.5 formats, will contain all pertinent information necessary for data analysis.

Analysis

For a Maxwellian distribution of electrons characterised by temperature T_{hot}, the thick-target bremsstrahlung radiation is approximated by

$$I = I_0 \exp(-h\nu / kT_{hot}) .$$

The total energy in hot electrons, E_{hot}, is related to the spectral intensity by

$$E_{hot} = \frac{1}{5\times10^{11}} I_{h\nu=kT_{hot}} \frac{79}{Z},$$

where E_{hot} is the total hot electron energy in J, $I_{h\nu=kT}$ is the spectral intensity [keV (keV 4π sr)$^{-1}$] at $h\nu = kT_{hot}$, and Z is the atomic number of the target material [1–3].

For incident laser energy E_L J, hot electron fraction f_{hot}, and a gold target (Z = 79) it follows that

$$I_{h\nu=kT_{hot}} = 5\times10^{11} f_{hot} E_L$$

keV (keV 4π sr)$^{-1}$,

and

$$I_0 = \frac{e}{4\pi} 5\times10^{11} f_{hot} E_L \quad \text{keV keV}^{-1}\ \text{sr}^{-1}.$$

Calibration

Initial calibration of the FFLEX device is based on material parameters, solid angles, estimated efficiencies and input from AWE. Absolute component calibration will be accomplished at a later date as an in house calibration facility comes on-line during the fourth quarter of 2004.

Signal expectations

The signal (charge-sensitive pre-amplifier output, in V) from each FFLEX channel is given by

$$V_n = \omega_1 \omega_2 S_n \int R_n(E) I(E) dE .$$

where: n is the FFLEX channel number; ω_1 and ω_2 are, respectively, the solid angle subtended by the FFLEX entrance aperture at the emission source, and the solid angle subtended at the scintillation detector by a point on the fluorescer foil (or, more accurately, the equivalent geometric coupling parameter);
S_n is a multiplying factor that determines channel the sensitivity (and depends on both the photomultiplier gain and pre-amplifier sensitivity); $R_n(E)$ is the energy-dependent channel response function;
$I(E)$ is the spectral intensity; and
E (= $h\nu$) is the photon energy.

We discuss the relation between x-ray spectrum, FFLEX sensitivity, and output signal for the AWE FFLEX. For a possible configuration of FFLEX at NIF, we use the familiar Kruer expression relating the hot-electron temperature, and total hot-electron energy, to the thick-target bremsstrahlung emission spectrum. We calculate FFLEX output signals for different candidate x-ray spectra, parameterised by laser energy, hot-electron energy fraction (f_{hot}), hot-electron temperature (T_{hot}), and hohlraum wall thickness. With FFLEX situated at 7 m from NIF target-chamber centre, approx. 10 kJ incident laser energy, and f_{hot} and T_{hot} in the range 1–10 % and 20–60 keV respectively, meaningful data can be recorded. FFLEX should be operated either in its current (AWE) configuration (for the lower x-ray spectral intensities), or with its present sensitivity reduced by up to (but not necessarily more than) an order of magnitude. An appropriate, modest, sensitivity reduction may be achieved by reduction of photomultiplier bias voltage, reduction of charge-sensitive pre-amplifier sensitivity, or reduction of the size of the aperture between fluorescer and scintillator.

I. FFLEX spectral response and sensitivity

We will work in the following system of units (and associated physical meaning):
ω_1, ω_2 sr (solid angle);
S_n V keV^{-1} (output voltage per unit absorbed energy at the scintillator, at the 59.5 keV photon energy we use for calibration);
$R_n(E)$ keV keV^{-1} sr^{-1} (energy per unit solid angle incident at the scintillator, per unit incident energy);
$I(E)$ keV keV^{-1} sr^{-1} (energy per unit spectral energy range, per unit solid angle).
Specific values of these quantities are as follows:
For 20 mm diam. FFLEX entrance aperture at 7 m distance from NIF target-chamber centre, we have
$\omega_1 = 6.4 \times 10^{-6}$ sr.
With the configuration of the FFLEX fluorescer and scintillator used at HELEN, we have
$\omega_2 = 5.4 \times 10^{-2}$ sr.
Values for the sensitivity multipliers, S_n, from a calibration of FFLEX (1250-V photomultiplier bias, 4700-pF pre-amp integration capacitors) are listed in Table 1. Clearly, the sensitivity can be varied significantly by variation of photomultiplier bias voltage, and charge-sensitive pre-amplifier integration capacitor (we typically use 22 pF for single-photon pulse counting for calibration, and 4700 pF and 22000 pF for laser-plasma experiments). Care should be taken not to run the photomultipliers into space-charge saturation, or significantly to deplete the dynode-chain capacitors and thereby affect the gain.
The individual channel response functions, R_n, for our current combinations of pre-filter, fluorescer, and post-filter foils, and NaI(Tl) scintillators (listed in Table 2) are shown in Figure 1.

III. Typical FFLEX signals for NIF early-light experiments

As a basis from which to scale to NIF experimental conditions, I have assumed 10 kJ laser energy, f_{hot} = 1%, and T_{hot} in the approximate range 20–80 keV. Scaling of the calculated FFLEX output signals to different laser energies, or different hot-electron fractions, is linear, for fixed T_{hot}. The low-energy x-ray spectrum is significantly attenuated by the hohlraum wall, so I have calculated FFLEX signals for two cases (no hohlraum wall, and 20-μm thickness hohlraum wall).

FFLEX output signals (for the 8 different FFLEX channels whose responses are illustrated in Figure 1) are shown in Figure 2.

IV. Discussion

This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

References

[1] R. L. Kauffman, LLNL memorandum XRM-78-43 (March 1978).

[2] V. Rupert, LLNL memorandum LFEG 81-28 (April 1981).

[3] R. P. Drake et al., Phys. Rev. A **40**, 3219 (1989).

---

1 Reference for HELEN is needed here

2 C.L. Wang, Rev. Sci. Instrum. 52(9), 1317 (1981)